

OBSERVATIONS OF CATAclySMIC VARIABLES WITH IUE*

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ABSTRACT

We report observations of the cataclysmic variables AN UMa, 2A0311-227, VV Pup, DQ Her, and GK Per made with IUE. We have been able to detect continuum emission in the short-wavelength (λ 1180-1950) region in DQ Her. This object exhibits a quasi-blackbody ($\sim \nu^2$) spectrum at short wavelengths; such blackbody components are a common property of the variables AM Her, SS Cyg, and U Gem, suggesting an underlying similarity in the activity of these diverse systems. "Flat" continuum components at longer wavelengths in general are not compatible with standard disk models. The emission line ratios in AE Aqr are anomalous, in that C IV is absent to a very low level relative to N V.

INTRODUCTION

Ultraviolet spectroscopy of cataclysmic variables is yielding a much different perspective on the nature of such objects than that obtained from optical and X-ray observations. In another paper (ref. 1) we have discussed the UV spectra of AM Her, SS Cyg and U Gem. Although these objects have quite different optical characteristics, they all exhibit blackbody components of UV emission with temperatures in the range 10 eV -40 eV. Here we examine the spectra of several other cataclysmic variables in order to study the ultraviolet emission through a wider range of stellar properties.

OBSERVATIONS

a) DQ Her

The object Nova DQ Her (1934) has been well studied photometrically and spectroscopically (refs. 2, 3, 4). Optically, it is a single-lined binary with a period of 4^h30^m. Periodic oscillations indicate that the white dwarf has a rotational period of 71 sec. Narrow emission lines arise from a nebular shell $\sim 20''$ in diameter; He II $\lambda 4686$ and high Balmer series lines follow the radial velocity variation of the hot object. These lines are doubled, with a separation ~ 650 km s⁻¹ (ref. 4), interpretable in the standard way as emission from a rapidly rotating disk.

In Fig. 1 we show a 165 min. exposure on DQ Her taken through the large aperture at low dispersion. The spectrum is composed of a curving continuum upon which emission lines of N V, C IV, Si IV, He II, and C II are superimposed.

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The line ratios are very similar to those observed in AM Her. In addition, the continuum shapes are similar in DQ Her and AM Her. The ubiquitous blackbody emission appears as a Rayleigh-Jeans distribution rising for $\lambda < 1500\text{\AA}$. The similar emission seen in AM Her, SS Cyg and U Gem was interpreted by Fabbiano *et al.* (ref. 1) as the result of nuclear burning of the accreted material.

Kraft (ref. 3) inferred the presence of an ultraviolet component with a blackbody temperature ~ 8 eV in an attempt to account for the $\lambda 4686$ emission by photoionization. Our results indicate a temperature ≥ 10 eV. However, we are unable to account for all of the $\lambda 1640$ emission by recombination following photoionization by the blackbody component. As discussed by Fabbiano *et al.* (ref. 1), if the ν^{-2} component of the continuum and the $\lambda 1640$ emission are both produced by optically thick cool gas illuminated by the black body, the $\lambda 1640$ equivalent width is a simple function of black-body temperature. The maximum predicted equivalent width is $\leq 15\text{\AA}$, while the observed value is 40\AA . Therefore either the emitting gas is optically thin to continuum radiation (ref. 5) or the $\lambda 1640$ emission is produced by a mechanism other than recombination following photoionization by the blackbody component.

One clear difference of the DQ Her spectrum from that of AM Her is in the line widths. In AM Her the emission in He II $\lambda 1640$ comes from a narrow component of 80 km s^{-1} width and a broad component $\sim 600 \text{ km s}^{-1}$ wide (ref. 6); this corresponds nicely with the optical observations of $\lambda 4686$ (ref. 7). The optical profile of $\lambda 4686$ in DQ Her is doublepeaked, with a separation of $\sim 650 \text{ km s}^{-1}$ between components (refs. 3, 4). The low-dispersion resolution of IUE is $\sim 1000 \text{ km s}^{-1}$ at $\lambda 1640$, so that it is difficult to determine the expected line width. The $\lambda 1640$ profile of DQ Her is marginally broader than that of AM Her, formally suggesting a line width $\sim 800 \text{ km s}^{-1}$, which is consistent with the optical data within observational errors.

However, there is no question that the C IV, Si V, and N V profiles are much wider in DQ Her than in AM Her. From the C IV and N V widths we estimate a velocity width $\sim 1400 \text{ km s}^{-1}$. Thus we have evidence of the manner in which the temperature of the disk decreases with increasing distance from the star.

The similarity of line strengths between AM Her and DQ Her, despite the fact that AM Her shows no evidence for a disk accretion pattern, demonstrates that the excitation of the ultraviolet emission is not controlled by the geometry of the flow.

We have also detected nebular emission from the expanding nova shell in C II $\lambda 1335$ and C III] $\lambda 1909$. The image of the $10'' \times 20''$ large aperture is barely visible on the photowrite image. From the line-by-line spectra we estimate fluxes of 4.7 and $1.2 \times 10^{-14} \text{ erg cm}^{-2} \text{ s}^{-1}$ in $\lambda 1335$ and $\lambda 1909$ respectively from about one-half of the nebula. We do not detect the C I $\lambda 1656$ emission predicted by Ferland and Turan (ref. 8), but the upper limit of $\sim 2 \times 10^{-14} \text{ erg cm}^{-2} \text{ s}^{-1}$ is within the two order of magnitude uncertainty of the prediction. The C II and C III emission probably arise from the relatively hot component of nebular gas which emits the [N II] and [O II] lines (ref. 9) rather than the cold, recombining gas, because recombination from the ground state of C III to the

$2s2p^2$ upper level of $\lambda 1335$ would require a two-electron transition.

b) AN UMa and GK Per

AN UMa is an "AM Her" type system, i.e. a 1- to 3-hour binary consisting of a magnetic ($10^7 - 10^8 g$) white dwarf accreting matter from a red dwarf. The SWP spectra of AN UMa, VV Pup and 2AO311-227 (the 3 AM Her types other than AM Her) all look remarkably similar when scaled with optical brightness.

The spectrum of AN UMa is shown in Fig. 2. While it has strong C IV, N V, and He II emission as in DQ Her, there appears to be little if any continuous emission. Rather, much of the spectrum appears to be composed of weak emission lines. This statement appears to be firm despite the low signal-to-noise ratio of the exposure on the basis of intercomparison of two separate exposures.

There is some evidence for an asymmetric profile of C IV in AN UMa as well as in DQ Her; with some extra emission on the short-wavelength side. What significance this asymmetry has is not known. The spectrum of 2AO311-227 is very similar to that of AN UMa.

In Fig. 3 we show the spectrum of the old nova GK Per (Nova Per 1901). Despite the weakness of the exposure, it is clear that the C IV emission is relatively weak viewed against the neighboring "pseudo-continuum" when compared with AN UMa. The emission structure appears to have similarities to AN UMa, particularly in a possible N V emission followed by an "absorption" dip $\sim 1250-1270\text{\AA}$.

Of particular interest is the rough similarity of the GK Per spectrum to that of the hot UV stellar source in the center of the globular cluster NGC 6624 which has been identified with the bursting X-ray source (ref. 10). Although the spectrum is again quite weak, multiple long exposures indicate some evidence for the "absorption" dip at $1250-1270\text{\AA}$ s as well as a general lack of prominent emission lines.

The nature of the spectra in AN UMa and GK Per suggest an optically thin emitting region in the accretion disk. Our interpretation of the blackbody component as the result of nuclear burning on the white dwarf suggests that the difference in short-wavelength continuum is primarily due to the differences in how the accreted material arrives on the white dwarf surface.

c) AE Aquarii

The short wavelength spectrum of AE Aquarii is much different from those of the strong emission line objects discussed above in that N V and Si IV are extremely strong, while C IV is barely detected. One possible explanation is an abundance anomaly. Another is an emitting region extremely optically thick in the lines, as discussed for the Balmer lines by Williams (ref. 5). The relative intensities of N V and C IV can be explained if the lines are formed at temperatures of 16,000K and 10,000K respectively, as might be expected for cool gas illuminated by X-rays (ref. 11). The emitting area required is sensitive to the temperatures of formation, but it is consistent with reasonable sizes for an accretion disk.

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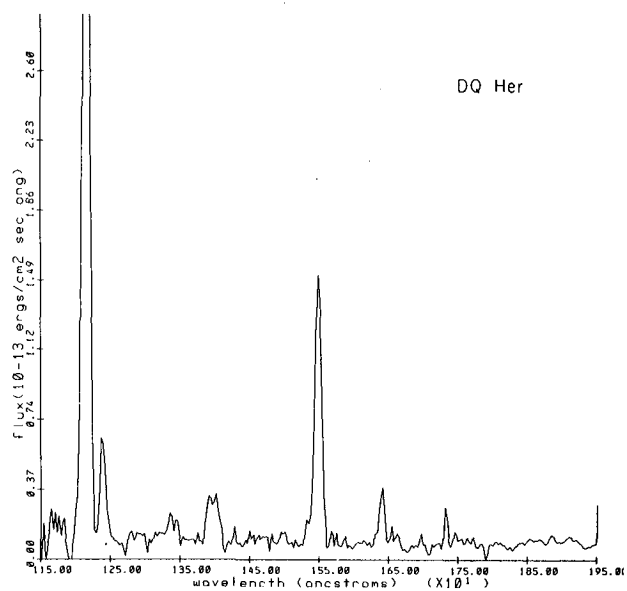


Figure 1

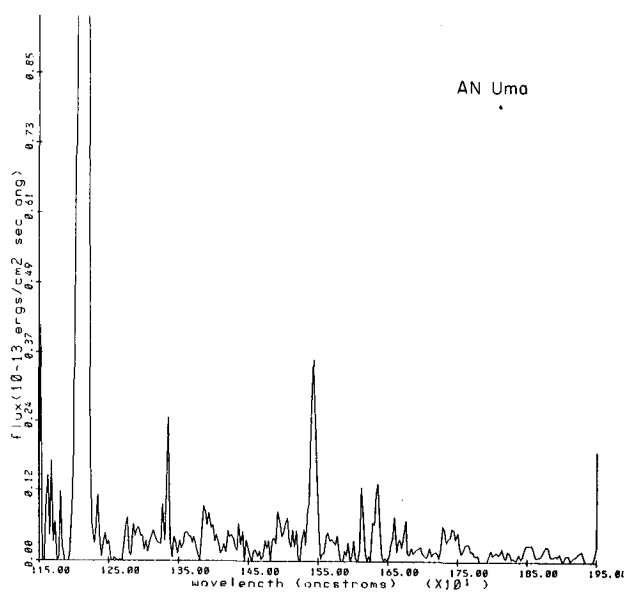


Figure 2

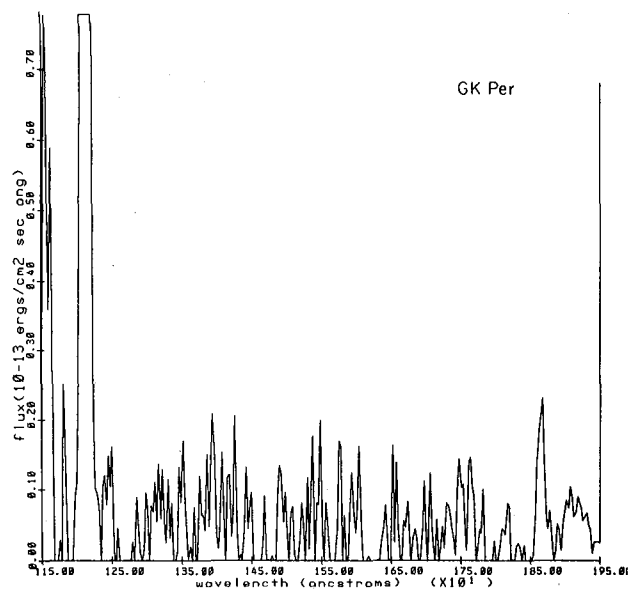


Figure 3